

NASA – Ames Research Center and Pipeline Research Council International, Inc.

Automated Monitoring of Pipeline Rights-of-Way

API Pipeline Conference

New Orleans, LA

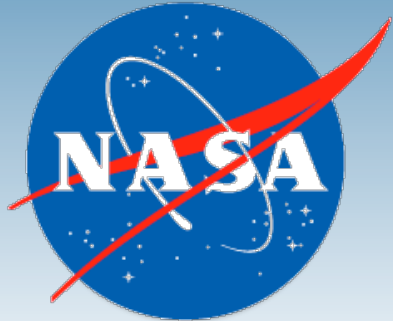
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Chad R. Frost

Manager, Autonomous Systems and Robotics

NASA Ames Research Center

Moffett Field, California



LEADING PIPELINE RESEARCH

Presentation Topics and Overview

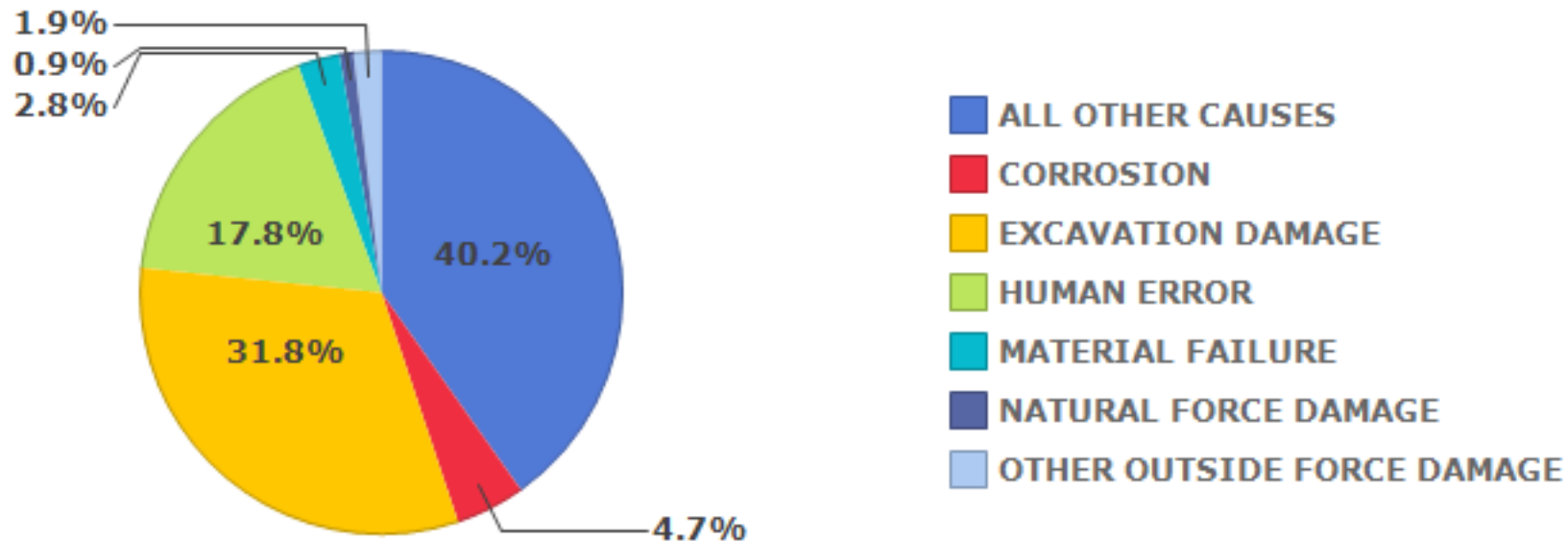
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- **Damage Prevention – Drivers & Challenges**
- **Successes of Current Research Programs**
- **Building on the Successes & Addressing the Next Series of Challenges for the R&D Community**

Causes of Damage to Pipelines

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Serious Incident Cause Breakdown
National, Hazardous Liquid, 1988-2008



Source: PHMSA Significant Incidents Files April 15, 2009

Outside force damage is the single greatest cause of pipeline failures

Mechanical Damage is single largest cause of on-shore pipeline damage

Damage Prevention – Why is This so Challenging?

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- **Substantial mileage of all SYSTEMS**

- 170,000 miles of hazardous liquid lines
- 295,000 miles of gas transmission lines
- 1,900,000 miles of natural gas distribution lines



- **Varying needs - unique conditions for each operator**
- **Monitoring Frequency and timing; resource limitations**
- **Accuracy and reliability of databases (upkeep)**
- **Sensitivity of Measurement systems**
- **Inherent difficulty in effective communication with multiple stakeholders and existing databases – DIRT, One Call, etc.**
- **“If You Build it They Will Come” – Increasing Encroachment**

Damage Prevention – Desired Solution

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- **No single technology can address all pipeline issues**
 - Tiered approach
 - Combination of multiple technologies
 - **GOAL: Develop one single, automated system, service or suite of technologies developed to apply over the entire pipeline system network to address:**
 - **Damage Prevention**
 - Leak detection
 - Changed Conditions
- RAM Program**

Current Operational Practice

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- Light aircraft (ex. Cessna 172)
- Flown low-and-slow (~500 ft AGL, 100 kts)
- Single pilot, sometimes with an observer
- No automation – pilot/observer looks out the window
- Calls in any threats observed



Photo credit: Prasetyo, M. Ector

Benefits:

- Reliable
- “Real-time”

Costs:

- Safety of pilot, aircraft
- Time-consuming
- Only “sensors” are pilot’s eyes
- No documentation of ROW state
- Coverage of ROW is not continuous

RAM Program Vision

Realize enhanced aerial surveillance of the ROW through a suite of cost-effective sensors and technologies to prevent infrastructure damage.

Project Objective

- Identify, validate and advance automated monitoring technology
- Implement near term solutions on manned aircraft - long term view to satellite and unmanned surveillance



Integrate sensors and technologies:

- ✓ Airborne Threat detection systems
- ✓ Near real-time detection & reporting
- ✓ Long range communications
- ✓ Multiple data systems
- ✓ Image archiving & management
- ✓ Predictive Modeling

Scope – Automated Detection

- ROW Encroachments/intrusions
- Machinery/spills underneath tree canopy
- Ground disturbances, erosion, etc
- ROW Leak Detection – Gas & Liquid Hydrocarbons

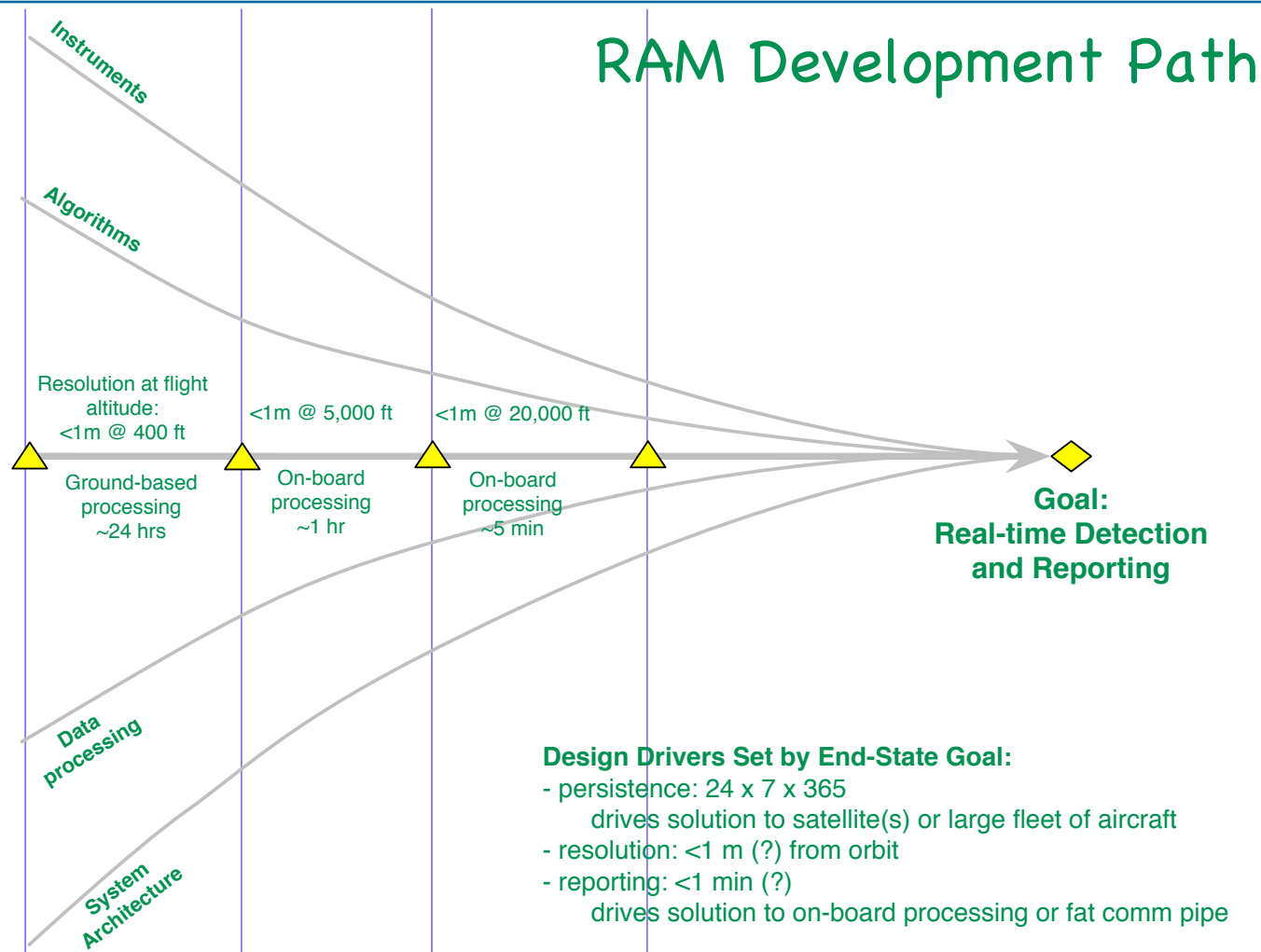
Benefits of RAM and Related R&D

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- Enhance community safety and environmental protection
- Increase pilot safety
- Increase pipeline integrity, security and reliability
- Significant improvement to efficiency and effectiveness of monitoring pipeline ROWs
- Augment ability to detect and respond to unauthorized excavations
- Reduce third party encroachments and incidents

RAM Program Overview

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RAM Program - Concept of Operations

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- Suite of sensors mounted on various aerial platforms to **detect** machinery threats (as well as other threats such as leaks and ROW changes)
- Automated recognition and identification of threats and **process** data on board aerial platform
- Via communication link (wireless, radio) **notify** operations center and/or designated field locations of threat with appropriate alarm indicating severity
- Download and **archive** data

Successes of our

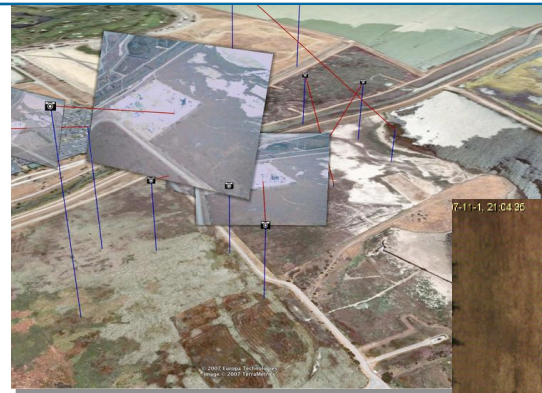
CURRENT RESEARCH

Damage Prevention - Machinery Threat

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■ Objectives

- Develop **technology** to enhance detection encroachment or intrusion along ROW
- Bulldozers, backhoes, drill/augers, and scrapers
- Improve efficiency, coverage and cost-effectiveness of patrol



Aerial sensors,
geo-referencing,
and computer
vision



■ Approach

- Automate **documentation** and **detection** tools
- Enhance current practice (manned patrols)
- Develop algorithms and prototypes for future flight systems

■ Schedule

- Phase 1: Collect data, evaluate sensors, develop algorithms & concept of operations (**completed**)
- Phase 2: Validate algorithms, prototype and test system in field (**current focus**)
- Phase 3: Refine, produce, and verify flight system

Threat Detection: Status

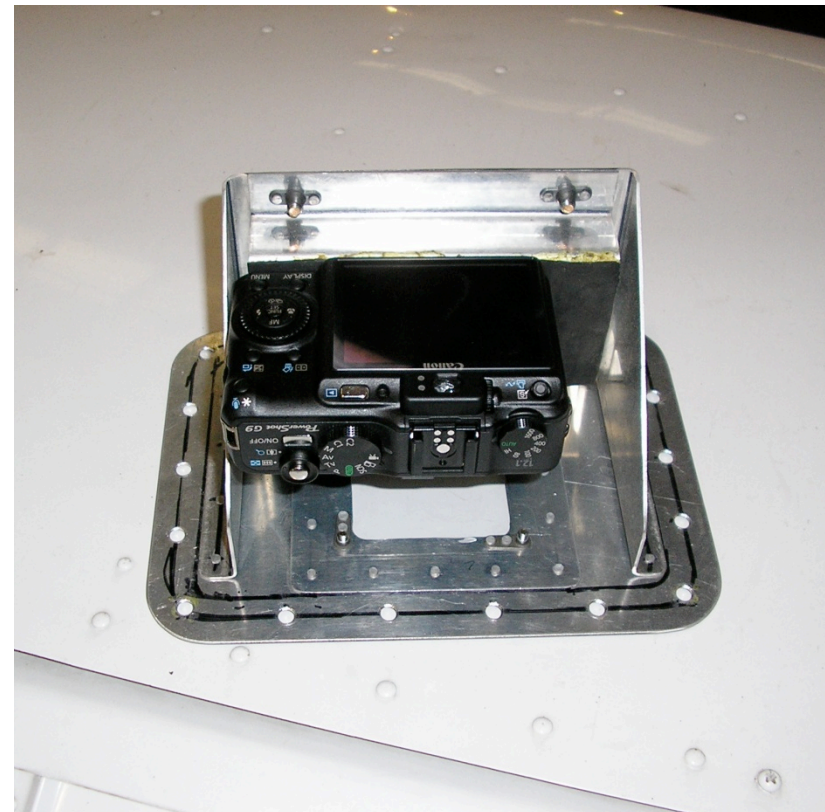
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- Developed an easily modifiable end-to-end proof-of-concept system for collecting imagery, consistently finding most threats, and objectively evaluating the system performance
- Developed prototype image collection system, using COTS camera with custom firmware and in-wing mount
- Worked with BP to conduct flight activities: collected ROW and Threat imagery, demonstrated system capabilities
- Threat detection algorithms were significantly improved, with most of the threats due to heavy digging equipment being correctly tagged (however, the false alarm rate is high)



Threat Imaging Technology Demonstrated

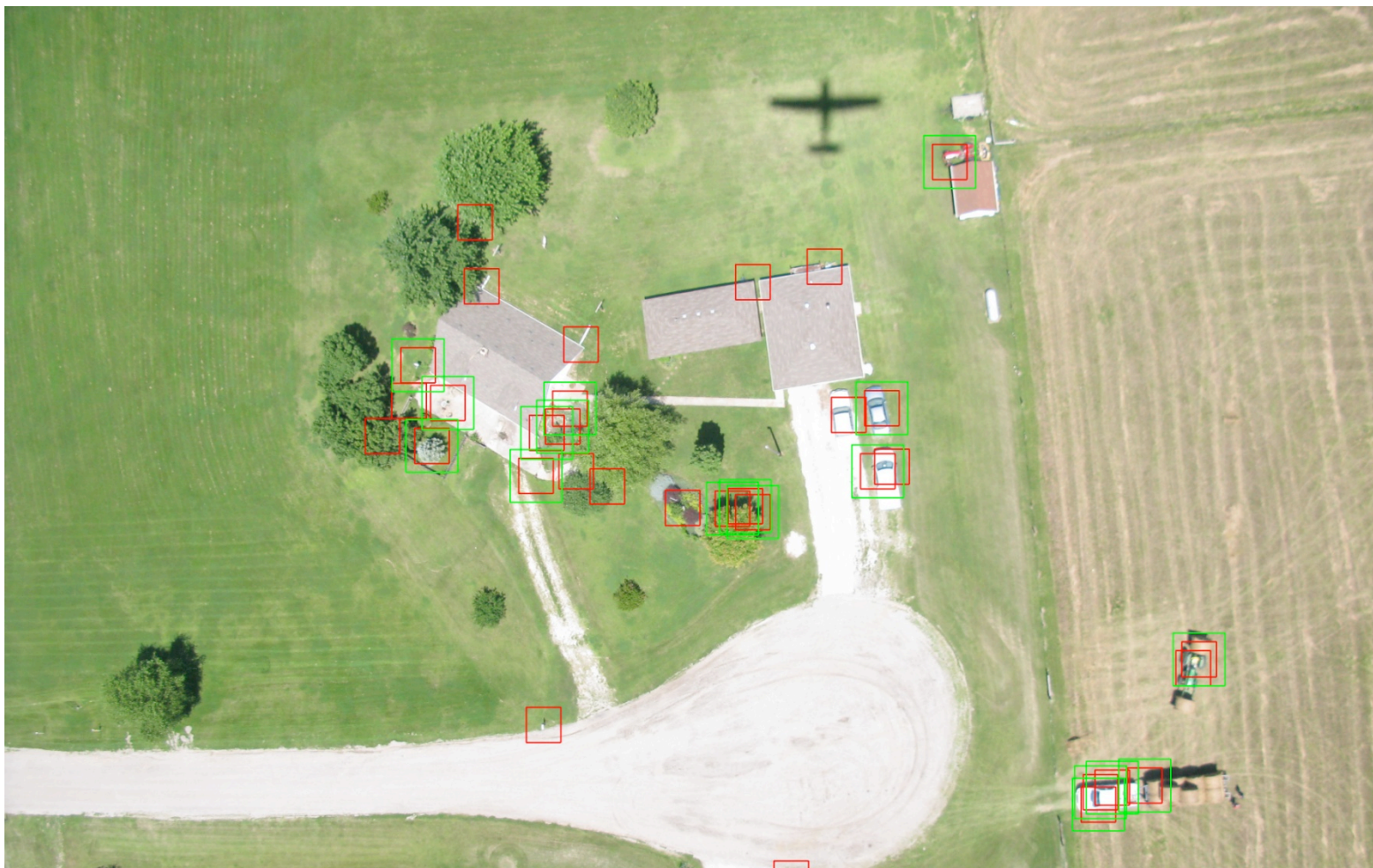
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Wing-mounted visual imaging camera – configure for current platform

Algorithm Successfully Identifies Threats

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Algorithm accurately identifies threats at high rate of detection

A good test case – no false positives!

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Damage Prevention – Leak Detection

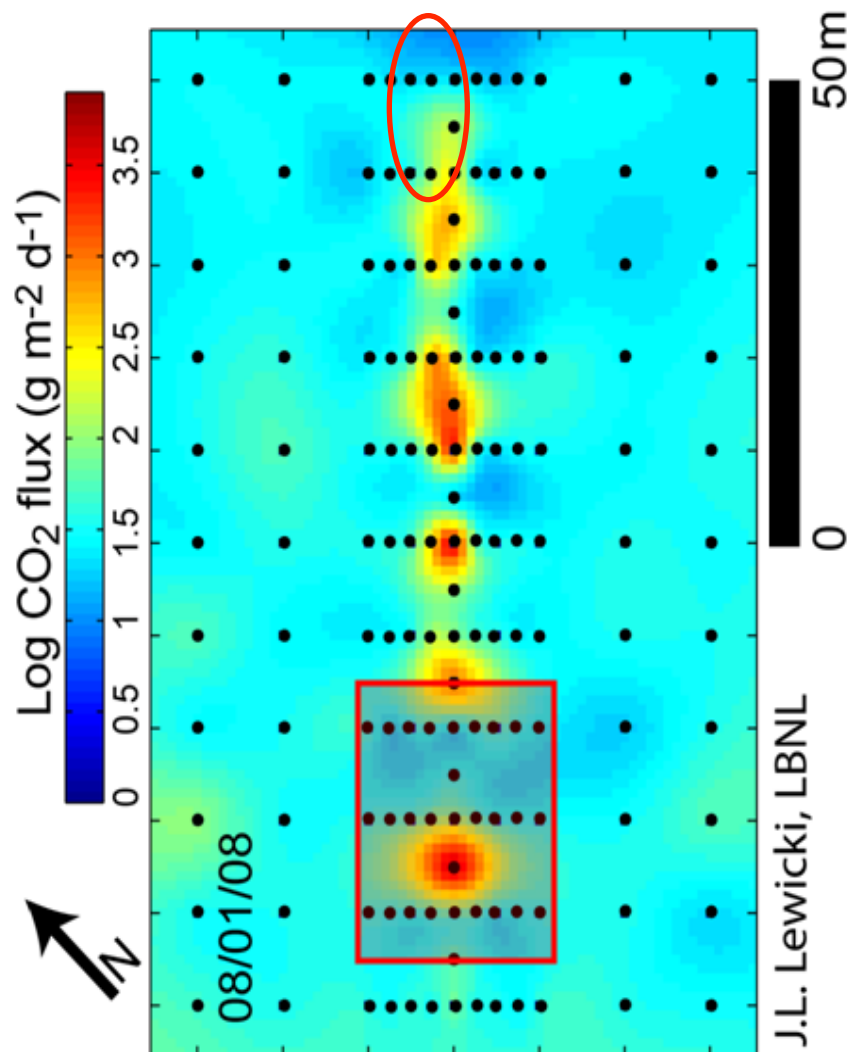
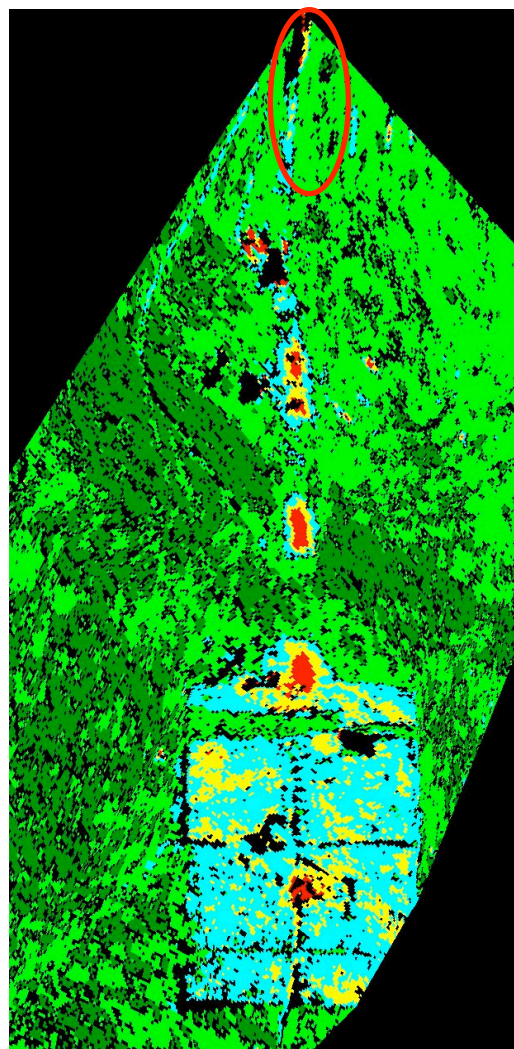
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- **Technologies for detection above ground are commercially available**
- **Project focused on *underground* detection**
 - **Developed an algorithm that automates hyperspectral airborne image analysis for underground gas leak detection utilizing plant stress response to CO₂**
 - **Automation algorithm matches results of manual analysis (using COTS ENVI software) almost identically**
 - ***The plant stress mapping technology is of high readiness***

Leak detection via plant stress response

Manual analysis results

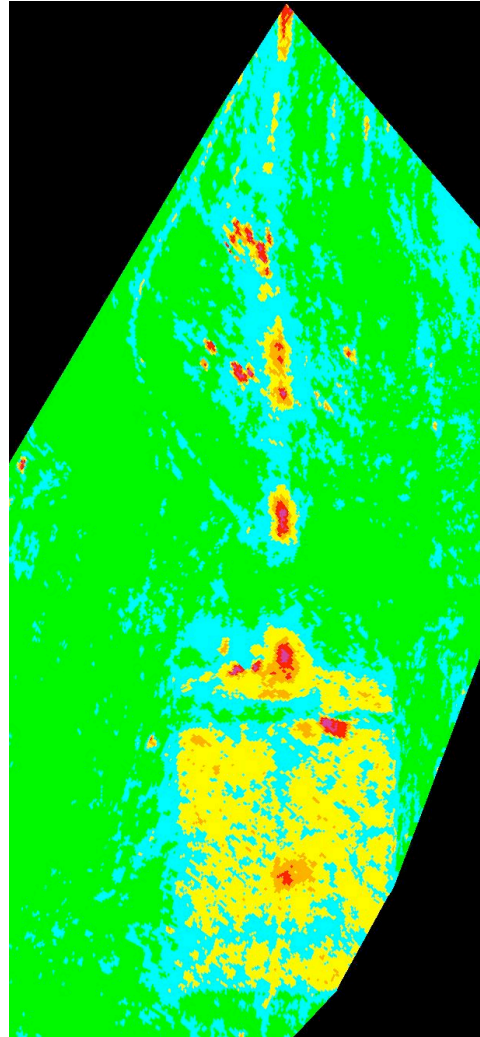
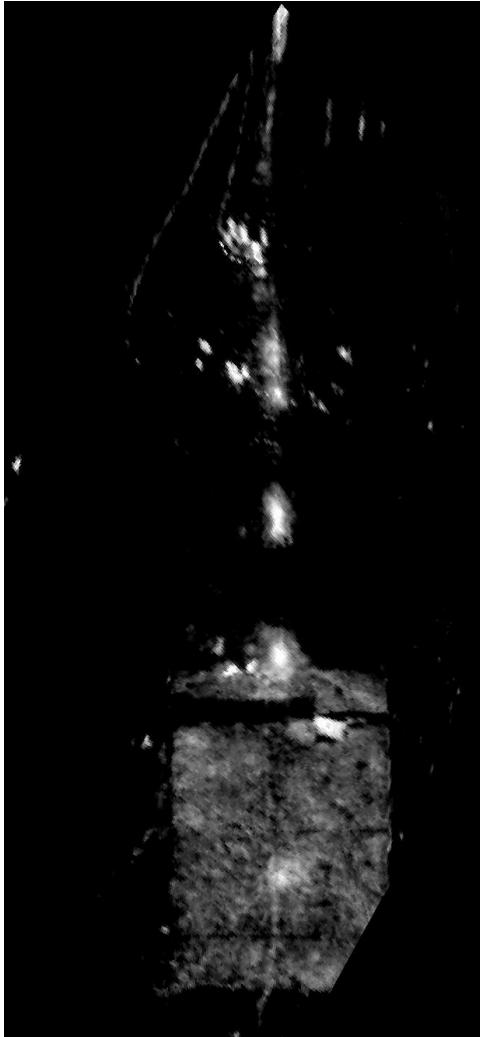
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Plant stress spots
correspond to
measured CO₂ flux
maxima

Semi-automatic notch depth analysis results

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**Black and white:
raw results**

**Colored:
brightness ranges mapped
to 6 color set**

**Red indicates leak or false
positive**

**False positives can be
discriminated based on
sharpness of edges and/or
using high resolution
photographs**

Information Gathering

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- Request for Information, RFI, announced through DOT – PHMSA
- FedBizOps RFI #DTPH56-09-1000001
- Solicited input on available technologies relevant to RAM program
- Has been, and is continuing to be, very successful
- 36 Responses to date, extended through 2010, and possibly through project life cycle
- Responses covered a range of sensors and technologies e.g.,
 - Full spectrum hyperspectral
 - Light Detection and Ranging
 - Morphology measurements (-vs- gas constituent detection via differential absorption)
 - Synthetic Aperture Radar (SAR)
 - Polarimetry
 - Magnetometry
 - Data Fusion / Hybridization
 - Imagery / Hyperspectral / Lidar / SAR
- *Responses are still solicited!*

Building on our successes... addressing the next
CHALLENGES

Challenges and Additional R&D Needs

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Sensors

- What are the minimum requirements?
 - Type
 - Resolution
 - Calibration & maintenance requirements
 - Payload limitations
- Sensor and computer miniaturization
- Automated sensors that detect machinery in various environments, terrains, and background conditions
 - Snow, grass, dirt, sand
 - Mountain, swamp, forest and variable terrains
 - Under tree canopy
 - Off-shore

Challenges and Additional R&D Needs

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Data Processing and Communications

Near-real time to real time

- Detection, analysis & processing; on-board systems
- Multiple sensors
- Dissemination and appropriate notification

Over the horizon, high band-width communications

Full integration with aircraft and ground systems

Data management and archiving challenges

Human factors

Evaluating Multiple Platforms

- Manned – near term focus
- Unmanned – mid to long term goal
- Satellite – long term goal

RAM Program plans

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- **In 2010, the program will focus on:**
 - Continued development and validation of machinery threat detection technologies
 - Development of a flyable prototype system
 - Continued evaluation and assessment of elements identified through the RFI process

RAM – Other Potential Benefits

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- **Enhance localized aerial surveillance**
- **Focus surveillance during spill/event**
 - Marine oil spill, wildfires, hurricanes
- **Security surveillance**
 - Refinery, tank farm or marine terminals
- **Threat detection and security for other linear industries or critical infrastructure**
 - Water, electric, highway, rail, communications

RAM Program: Summary

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PRCI, in collaboration with NASA, has successfully implemented a research program that is focused on overcoming the key gaps for automated right-of-way monitoring:

- Developing and testing systems capable of detecting heavy equipment threats and underground leaks
- Defining operational requirements
- We are *not* focusing on elements that are easily procured
- Significant challenges remain to be addressed
- The fundamental technologies being developed and tested are of broad value to NASA and the nation

RAM Program

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- **Questions**